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Practical Issues in Monetary Policy Targeting

by Stephen G. Cecchetti

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Introduction

What do monetary policymakers need to know and when do they need to know it? Textbook descriptions and academic discussions of policymaking usually ignore the practical problems faced by those who make the decisions and take the actions. While most economists would agree that monetary policy has real short-run effects and is most likely neutral in the long run, they could provide no more than informed speculation in helping decide at what level to set the target for a policy instrument and when to change it.

This paper's purpose is to outline the type of information monetary policymakers need in practice, and to examine the data to see what we actually know.[1] Any policy rule must be formulated in several clearly defined steps. First, one must identify an operational instrument, best thought of as something policymakers can control precisely, like the federal funds rate or the monetary base. Next, there must be a target. Many central banks have stated that price stability is their goal, but an obvious alternative to targeting the aggregate price level is targeting nominal income.[2] In addition to choosing the target variable itself, formulating policy necessitates specifying a loss function: What is the relative importance of large and small, or positive and negative, deviations of aggregate prices from their target path? One might also assign a cost to large movements in the target variable. For example, it might be important for the Federal Reserve to have a reputation for changing the federal funds rate target smoothly, without large movements or sudden reversals, to avoid creating uncertainty in financial markets.

The next stage in devising a monetary rule is to link the operating instrument with the target. This requires specification and estimation of a macroeconomic model. One needs quantitative answers to questions of the form "If the federal funds rate is moved by one percentage point, what will be the path of the aggregate price level and real output over the following three years?" Not only do we require a point estimate of this response function, but it is also crucial that we know how precise our knowledge is in a statistical sense.

■ **1** This work is based on Cecchetti (1995).

■ **2** I will not discuss the difference between price-level and inflation targeting. While this is a potentially important practical distinction, it is beyond the scope of this paper.

Finally, policymakers need a timely estimate of their target variable's future path *in the absence of* any policy actions. In other words, they must know when external shocks hit the economy, how large they are, and what their impact on the time path of aggregate prices and real output will be.

The next section offers a detailed discussion of the modeling issue: How do we formulate and estimate the necessary simple, dynamic, empirical macroeconomic model? The section's first major part looks at econometric identification. What must we assume in order to disentangle the fluctuations in output and prices into their various components? How might we actually estimate the impact of monetary policy on macroeconomic quantities of interest?

The section's second major part discusses the issue of structural stability. Monetary policymakers change their emphasis fairly frequently, focusing on one indicator one year and another the next. How does this affect our attempt to estimate the relationship between the variables that policymakers control (like the federal funds rate) and the things we care about? Can we estimate a stable relationship between output, prices, and interest rates over any reasonable period?

The methodological discussion of modeling issues is followed by section II, in which I present a particular model and examine its properties. Several different types of results are included. First, I look at the impact of different sources of shocks on the variables of interest. Besides allowing answers to questions like "If the federal funds rate were to rise by 100 basis points, how much would output change over the next three years?" this approach makes it possible to examine the sources of fluctuations in output and prices. For example, has monetary policy been responsible for a significant share of output variation over the past decade?

Section III discusses how a policy rule can be formulated. The first step is to specify an objective function: What do policymakers actually want to stabilize? This discussion emphasizes the need for taking account of imprecision when forming a policy rule. We are uncertain how changes in the interest rate affect the size and timing of output and price movements. This means we cannot confidently predict policy actions' impact on target variables, so that policy actions differ from what they would be if we had perfect knowledge. From the theoretical discussion, I move on to examine several possible objective functions of policy and the interest rate paths implied by the combination of each rule and the estimated model. I focus throughout on the importance of employing rules that recognize the imprecision of our knowledge regarding the size of the linkages we need to estimate.

I reach three significant conclusions: First, since prices take time to respond to all types of economic shocks, the objective of price stability implies raising the federal funds rate immediately after a shock, instead of waiting for prices to rise. Second, and more important, comparing the results of price-level targeting with those of nominal-income targeting implies that the difficulties inherent in forecasting and controlling the former provide an argument for concentrating on the latter. Finally, it is possible to use policy rules to see how closely recent movements in the federal funds rate conform to those implied by either price-level or nominal-income targeting rules. The results show that the policy that is optimal in this limited sense involves faster, bigger movements than those shown by the actual federal funds rate path. This suggests that policymakers' actions have been based on something akin to nominal-income targeting, but with costs attached to interest rate movements.

I. Modeling Issues

The single biggest problem in formulating monetary policy rules is how to construct an empirical macroeconomic model that describes the critical aspects of the economy. It is important that the model be dynamic, summarizing the impacts of shocks to the economy—as well as those of intended policy actions—over time. The standard response to this challenge has been to construct various forms of vector autoregressions (VAR). A VAR can answer a question of the following type: "If the federal funds rate moves, when and by how much does the price level change?" Policymakers require quantitative answers to exactly these kinds of questions.

To construct any usable empirical model, a researcher must make a number of choices. I will describe four of these: 1) Which variables should be included in the model? 2) What is the appropriate measure of monetary policy? 3) How can the model be identified econometrically? and 4) Over what sample period should the model be estimated?

Variable Inclusion

When trying to discern the relationship between inflation, output, and monetary policy, should we include other variables in the model? Our answer is guided by the findings of Sims (1992), who estimates a model with prices, output, and an interest rate for several countries. His robust overall conclusion is that with this specification, increases in the interest rate (which should signal policy contractions) lead to prices that are higher than otherwise expected, not lower. This problem, which came to be known as the "price puzzle," can be eliminated by including commodity prices in the model. The reasoning is that the policymaker has additional knowledge about prices' future path that the three-variable model does not adequately summarize. Policy contractions, being based on this omitted information, signal that these other indicators are pointing toward higher prices.

More recent research, like that of Christiano, Eichenbaum, and Evans (1996a, 1996b), has shown that including commodity prices eliminates the puzzle. They suggest that higher commodity prices mean higher future overall prices, and that policymakers respond to this. In other words, an upward move in commodity prices precedes both a rise in the price level and a tightening of policy in the form of an increase in the federal funds rate. The omission of this information from the original Sims formulation led to a bias in which contractionary policy predicts higher aggregate prices. This is not a policy change, but simply a reaction to external events. The models of Christiano, Eichenbaum, and Evans do have the following property: Moving toward a more contractionary monetary policy drives prices down (relative to the trajectory they would follow without the policy change).

Choice of Policy Instrument

Beyond the question of which variables the model should include, it is necessary to specify a monetary policy instrument. Should one assume that policymakers are focusing on the federal funds rate itself (or behaving as if they were), or would it be more realistic to use nonborrowed reserves as the instrument? The literature takes up this issue in some detail.[3] Because events of the past 15 years suggest that the primary focus has been on the federal funds rate, I will assume that it contains the information necessary to gauge policy actions.[4]

Identification

A model builder's most complex decision is formulating a set of "identifying assumptions." This is also the subtlest issue and the one that has generated the most discussion in the literature. It is like the textbook question about estimating supply and demand curves: There, if data on the price and quantity of a good in a market both move, we cannot tell whether the root cause of the change was a shift in supply or a shift in demand. Here, things are a bit less transparent, because there are no clearly defined supply and demand curves in the standard microeconomic sense. Instead, it is necessary to distinguish whether prices, output, and interest rates moved as a result of policy shifts, or because of factors like changes in the price of oil (an aggregate supply shock) or in the demand for money (an aggregate demand shock).

To understand the problem and its solution more fully, we can begin by writing down a dynamic structural model in its moving-average form:

$$(1) \quad p_t = A_{11}(L)\varepsilon_{pt} + A_{12}(L)\varepsilon_{ct} + A_{13}(L)\varepsilon_{yt} + A_{14}(L)u_t$$

$$(2) \quad p_t^c = A_{21}(L)\varepsilon_{pt} + A_{22}(L)\varepsilon_{ct} + A_{23}(L)\varepsilon_{yt} + A_{24}(L)u_t$$

$$(3) \quad y_t = A_{31}(L)\varepsilon_{pt} + A_{32}(L)\varepsilon_{ct} + A_{33}(L)\varepsilon_{yt} + A_{34}(L)u_t$$

$$(4) \quad r_t = A_{41}(L)\varepsilon_{pt} + A_{42}(L)\varepsilon_{ct} + A_{43}(L)\varepsilon_{yt} + A_{44}(L)u_t\,,$$

where p_t, p_t^c, and y_t are the logs of the aggregate price level, commodity prices, and output, respectively, r_t is the policy indicator, the ε's are exogenous shocks, and u is the policy innovation. Equations (1)–(4) summarize the impact of all the shocks to the economy. The $A_{ij}(L)$'s are lag polynomials in the lag operator L. For example,

$$A_{11}(L)\varepsilon_{pt} = \sum_{i=0}^{\infty} a_{11i}L^i\,\varepsilon_{pt} = a_{110}\varepsilon_{pt} + a_{111}\varepsilon_{pt-1} + \dots\,.$$

3 See, for example, discussions in Christiano, Eichenbaum, and Evans (1996a, 1996b) and Bernanke and Mihov (1995).

4 Most results are unaffected by the substitution of nonborrowed reserves, suggesting that the funds rate elasticity of reserve demand is relatively stable.

Because we do not observe the shocks, it is not possible to estimate the model (1)–(4) directly. Instead, we estimate the more familiar VAR form and place restrictions on the coefficients (the a_{ijk}'s) in order to recover estimates of the shocks.

Identification entails determining the errors in this four-equation system, that is, the actual sources of disturbances that lead to variation in prices, output, and interest rates. As the appendix to this paper describes, when there are four endogenous variables, six restrictions are required for complete identification.

All identification schemes involve assumptions about how these sources of variation are correlated. Researchers use two types of restrictions for this purpose. The first, based on the pioneering work of Sims (1980), is what I will call a "triangular identification," which assumes that a shock does not affect a variable contemporaneously, and so one or more of the a_{ij0}'s are zero. For example, it is commonly assumed that no variable other than policy itself responds to monetary shocks immediately, and so $a_{140} = a_{240} = a_{340} = 0$.

A more formal description of a triangular identification begins by writing the matrix $A(0)$ that is composed of all the coefficients of the $A_{ij}(0)$'s—that is, all the a_{ij0}'s. Triangular identification means assuming that six of these a_{ij0}'s are zero, and so

$$(5) \qquad A(0) = \begin{bmatrix} a_{110} & 0 & 0 & 0 \\ a_{210} & a_{220} & 0 & 0 \\ a_{310} & a_{320} & a_{330} & 0 \\ a_{410} & a_{420} & a_{430} & a_{440} \end{bmatrix}.$$

In other words, triangular identification means that the monetary policy shock u_t is identified by assuming that no variable other than the federal funds rate responds to it contemporaneously. The output shock, ε_{yt}, is identified by assuming that it is the portion of the error in the output equation that is orthogonal to the policy shock, while the commodity price shock, ε_{ct}, is the portion of the error in the commodity price equation that is orthogonal to these. The final part of the residual in the aggregate price equation that is orthogonal to all three of these is the aggregate price shock, ε_{pt}.

There are many other ways to constrain the four-variable VAR and achieve identification. One, based on the work of Galí (1992), combines two types of restrictions. The first are contemporaneous and resemble those used in the triangular method. The second, following Blanchard and Quah (1989), assume that some shocks have temporary, but not permanent, effects on some variables. For example, we might claim that monetary shocks have no long-run effects on real output, and so the impact of u_t on y_t dies out. Formally, this involves assuming that the a_{34k}'s sum to zero: $\sum_{k=0}^{\infty} a_{34k} = 0$.

Recalling that we need six restrictions, the Galí-style procedure begins with two contemporaneous restrictions based on the logic of data availability and the time people in the economy take to act. The first constraint is that monetary policy does not affect real output contemporaneously (within the month). In the notation used above, the assumption is that $a_{340} = 0$. This seems sensible, since production planning is unlikely to change suddenly after a policy innovation. The second constraint is that the aggregate price level does not enter the money supply rule. This also seems sensible, because the Bureau of Labor Statistics does not publicly release the Consumer Price Index (CPI) until the month following its price survey.

The Galí-style, long-run restrictions, based on Blanchard and Quah (1989), amount to assumptions that neither monetary policy nor aggregate price (other aggregate demand) shocks permanently affect real output or the real commodity price level.

Together, the two contemporaneous and four long-run restrictions allow us to estimate the impact of monetary policy shocks on prices and output.

Structural Stability

Variable inclusion and identification are related. The way in which we name various estimated shocks in a model obviously depends on the quantities being modeled in the first place. While connected to the other choices, the final, more general issue concerns the period over which the empirical model is estimated. The problem is that the reduced-form relationships in the data are unlikely to be stable over any reasonable sample.[5] The problem, known widely as the Lucas (1976) critique, is that policy rule changes alter the relationship among endogenous variables in the economy.

It is easy to see why this might happen. For the sake of discussion, assume that inflation is actually determined by the following structural model:

$$(6) \qquad \pi_{t+1} = \alpha r_t + \beta_1 X_{1t} + \beta_2 X_{2t} + \omega_{t+1},$$

■ **5** For a more detailed discussion, see section 4 of Cecchetti (1995).

where r_t is policy, ω_{t+1} is a random variable, and X_{1t} and X_{2t} are measures of general economic conditions, like things that influence aggregate supply and money demand.

Next, assume that we can write down a reaction function whereby policymakers automatically change their policy control variable when economic conditions change:

(7) $r_t = \gamma_1 X_{1t} + \gamma_2 X_{2t} + \nu_t.$

The policymaker's role is to choose γ_1 and γ_2, the reaction of r_t to X_{1t} and X_{2t}. Since the γ's can be zero, a policy regime need not react to the X's. The term ν_t is a measure of the random component in the policy rule.

Now, consider the reduced-form regression:

(8) $\pi_{t+1} = \phi_1 X_{1t} + \phi_2 X_{2t} + \xi_t.$

Since $\phi_i = \alpha\,\gamma_i + \beta_i$, changes in policy, which are changes in the γ's, will alter the correlation between the X's and π. In effect, the reduced-form inflation regression subsumes the monetary-policy reaction function (7), so that a change in the monetary authorities' policy rule—which may be a change in the relative weight placed on various indicators—will cause changes in (8).

As a practical matter, there are several ways to deal with the instability that may be caused by changes in monetary policy rules. First, one can use institutional information to restrict the data to a period when there were no large changes in policy procedure. Second, one can try to estimate the timing of structural breaks.[6] Alternatively, one can use time-varying parameter models, as Sims (1992) suggests. It is also possible to simply ignore the problem and use all of the available data.

Following my earlier work, I use only the past decade's data, beginning in 1984. Excepting the truncated sample period, I will ignore the problems created by the Lucas critique in all of the calculations that follow. This is an unfortunate necessity if any progress is to be made.

II. Results from Estimating the Model

Impulse Response Functions

Using monthly industrial production data for January 1984–November 1995, the CPI for urban wage earners (CPI-U), the *Journal of Commerce* index of industrial materials prices, and the federal funds rate, along with the triangular identification in equation (5), straightforward procedures yield estimates of the a_{ijk}'s, as well as a covariance matrix for these estimates. These are the time path of the impact of innovations on the model's endogenous variables. They tell us how any one of the four shocks will affect any of the four variables initially—and after several months.

It is easiest to present these results in a series of figures. Figure 1 shows estimates of 16 impulse response functions, plotted with two standard-error bands.[7] These are the response of output, aggregate prices, commodity prices, and the federal funds rate to a unit innovation to each of the four shocks.

The impulse response functions are straightforward and easy to understand. Taking the policy innovation as an example, the last column of figure 1 shows the result of an unanticipated 100-basis-point change in the federal funds rate for one month on y_t, p_t, p_t^c, and r_t over the next three years. For example, the fourth plot in the third row shows the impact of monetary policy shocks (u_t) on the aggregate price level (p_t). The estimates suggest that a one-time policy tightening—an increase in the federal funds rate—causes prices to rise slightly initially, then to fall below their original level after about six months. Over the next 30 months, the price level continues to fall. The standard-error bands on this figure imply that we are actually *very* unsure of the response. The data indicate a strong possibility that the policy tightening will result in a price-level increase.

Several additional features of figure 1 are worth noting. First, in all cases, commodity prices (second row) respond more quickly and in the same direction as aggregate prices (third row). Second, for the three ε shocks, the output response seems to be more precisely estimated

6 This is the technique used in Cecchetti (1995).

7 The standard-error bands in the figure are constructed using the simple Taylor-series approximation:

$$F(\hat{\beta}) \approx F(\beta) + \frac{dF(\beta)}{d\beta}\bigg|_{\beta=\hat{\beta}} (\hat{\beta} - \beta),$$

where F is any differentiable function. The variance of $F(\hat{\beta})$ follows immediately as

$$E\left[F(\hat{\beta}) - F(\beta)\right]^2 \approx \left[\frac{dF(\beta)}{d\beta}\bigg|_{\beta=\hat{\beta}}\right]^2 Var(\hat{\beta}).$$

Here, we can think of the estimated impulse response functions, the $\hat{A}_{ij}$'s, as functions of the estimated reduced-form VAR coefficients, the elements of $\hat{R}(L)$. Given the estimated variance of these coefficient estimates, the variance of the $\hat{A}_{ij}$'s can be computed by numerical differentiation.

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FIGURE 1

Impulse Response Functions: Triangular Identification[a]

a. Estimated response, with two standard-error bands.

NOTE: Horizontal axes are in months; vertical axes are in the change in the log per month.

SOURCE: Author's calculations.

than the aggregate price response. This second conclusion is consistent with Cochrane's (1994) observation that real output is forecastable with high R^2 at horizons of several years, and with my finding (see Cecchetti [1995]) that inflation is difficult to forecast at horizons longer than a single quarter.

It is very tempting to seek a correspondence between the shocks in this four-variable VAR and those discussed in macroeconomics textbooks. In a simple model, the basic result is that aggregate supply shocks move prices and output in opposite directions, while aggregate demand shocks move them in the same direction. With this categorization, the impulse responses shown in figure 1 suggest that all of the shocks in this model come from the demand side. While this makes intuitive sense for the monetary policy shock, it renders the other classifications unsatisfactory.

One can either accept this at face value or ask whether it might result from the identification used to generate the estimates. Taking the second possibility seriously leads to examination of an alternative identification—the one proposed by Galí being a natural choice. Figure 2 plots the impulse response functions from such a model, estimated using exactly the same data. Because of the technical difficulty associated with their construction, I do not include standard-error bands. Here, the results differ markedly. It now appears that the output shock, ε_{yt}, behaves like an aggregate supply shock, while the three remaining shocks, representing the aggregate price-level shock, the raw material price shock, and the monetary policy shock, lead to reactions consistent with those expected from aggregate demand shocks.

However, we can draw an important positive conclusion by comparing these two sets of identifying restrictions: The impulse response functions of the monetary policy shock are robust to changes in the identification procedure. Policy's impact on output and prices seems fairly robust to the exact methods used in estimation. Since they are easier to compute, I will now proceed using only the estimates obtained with the simpler triangular identification.

Historical Decompositions

While the ultimate goal is to use the estimated dynamic model to construct policy rules, the impulse response functions and structural innovations also allow us to compute the quantities known as "historical forecast decompositions." These allocate output and price movements into the portions accounted for by each of the structural shocks. It is easy to understand how these estimates are constructed from the structural model's equations (1)–(4):

Define the impact of the monetary policy shock on output as $H_{yu}(t)$. From equation (3), this is just

$$(9) \qquad H_{yu}(t) = \sum_i^{\infty} a_{34i} u_{t-i},$$

and analogously for the other shocks. Its estimated value, constructed from the parameter estimates, is

$$(10) \qquad \hat{H}_{yu}(t) = \sum_i^{\infty} \hat{a}_{34i} \hat{u}_{t-i},$$

where $\hat{u}_t$ is the estimated monetary policy innovation.

Figure 3 plots the decomposition of the movements in real output and aggregate prices into the components attributable to monetary and nonmonetary shocks. In constructing these, I have truncated the sum in (9) at 60 months. Because of the difficulty in identifying innovations from nonmonetary sources, it seems prudent to simply sum them together. That is, I plot the fluctuations in y_t and p_t attributable to u_t, $\hat{H}_{yu}(t)$, and $\hat{H}_{pu}(t)$, and the portion not attributable to policy, $[y_t - \hat{H}_{yu}(t)]$ and $[p_t - \hat{H}_{pu}(t)]$.

The results show that, for the past seven years, important movements in both output and prices are largely accounted for by innovations other than those coming from monetary policy. The blue line representing $\hat{H}_{yu}(t)$ and $\hat{H}_{pu}(t)$ in the figure's two panels has much less variation than the green line representing the fluctuations in y_t and p_t that are attributable to nonmonetary policy shocks. This result is particularly striking for prices, where variation seems to be driven by innovations to output, raw materials prices, and the aggregate price level itself. Aggregate supply shocks and nonmonetary aggregate demand shocks account for most of the recent movements in key macroeconomic variables.

III. Formulating a Policy Rule

Issues

The main use of the empirical model described in section I and estimated in section II is to provide quantitative answers to the questions required for implementing a policy rule. To see

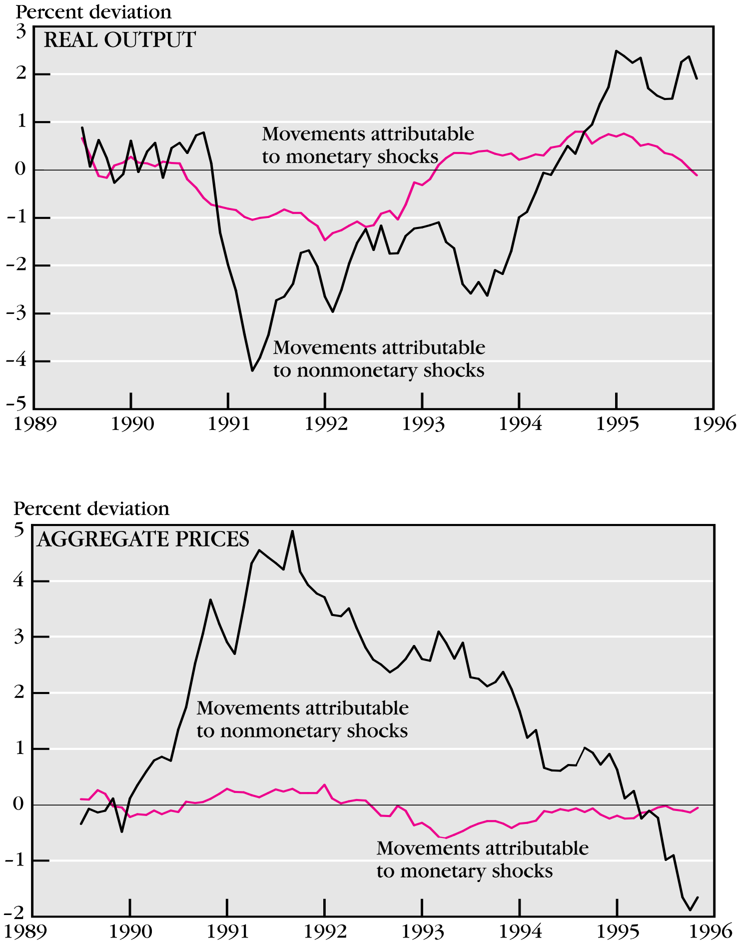
FIGURE 2

Impulse Response Functions: Galí Identification[a]

a. Estimated response.
NOTE: Horizontal axes are in months; vertical axes are in the change in the log per month.
SOURCE: Author's calculations.

FIGURE 3

Forecast Error Attributable to Various Innovations



SOURCE: Author's calculations.

how this is done, first note that the model implies estimated values for the aggregate price level and real output:

$$(11)\qquad \hat{p}_t = \hat{A}_{11}(L)\,\hat{\varepsilon}_{pt} + \hat{A}_{12}(L)\,\hat{\varepsilon}_{ct} + \hat{A}_{13}(L)\,\hat{\varepsilon}_{yt} + \hat{A}_{14}(L)u_t,$$

$$(12)\qquad \hat{y}_t = \hat{A}_{31}(L)\,\hat{\varepsilon}_{pt} + \hat{A}_{32}(L)\,\hat{\varepsilon}_{ct} + \hat{A}_{33}(L)\,\hat{\varepsilon}_{yt} + \hat{A}_{34}(L)u_t.$$

A policy rule is a sequence of u_t's that is constructed to meet some objective. In other words, the policymaker is allowed to pick the path of the federal funds rate to meet a particular objective.[8]

The monetary policy literature includes many discussions of the efficacy of various objective functions. Mankiw (1994) includes several papers that deal with this topic explicitly. There are two primary candidates: price-level targets and nominal-income targets. One version of these involves setting the policy instrument—the u_t's in the model—to minimize the average expected mean square error (MSE) of either inflation or nominal-income growth over some future horizon. In the inflation case, the objective function can be written as

$$(13)\qquad \min_{\{u_i\}} \frac{1}{h}\sum_{i=1}^{h} E(\hat{p}_i - p_o)^2,$$

where p_o is the log of the base-period price level and h is the policymaker's horizon. The expectation in (13) is over the sampling distribution of $\hat{p}$, which is related to the covariance matrix of the estimated coefficients in equation (11). Nominal-income targeting simply replaces the log price level in (13) with the sum of p_t and y_t.

One important distinction between the objective function (13) and more standard formulations is the treatment of parameter uncertainty. As the results in figure 1 clearly show, we are very unsure about the size and timing of price movements following innovations to the federal funds rate. When constructing a policy rule, it seems prudent to account for this lack of knowledge.

As Brainard (1967) originally pointed out, the presence of uncertainty has important implications. This is easily demonstrated in the present context. Consider a simplified version of the structural price and interest rate equations

$$(14)\qquad p_t = \varepsilon_{pt} + \gamma u_t$$

$$(15)\qquad r_t = u_t,$$

where γ is a parameter. Next, take the horizon in (13) to be one period (h = 1), and the initial log price level to be zero, p_o = 0. The policy control problem then reduces to

$$(16)\qquad \min_{\{u_i\}} E[\hat{p}_i^2].$$

Substituting in the expression for p_t, this is simply

$$(17)\qquad \min_{\{u_i\}} E[\varepsilon_{pi} + \hat{\gamma}u_i]^2.$$

8 Feldstein and Stock (1994) examine an identical experiment, but without parameter uncertainty.

If we ignore that γ is estimated, then it is trivial to generate the policy rule. It is just

$$(18)\quad u_i^* = -\frac{1}{\hat{\gamma}}\varepsilon_{pi}.$$

Taking account of uncertainty in the estimate of γ, but continuing to assume that ε_{pt} is known, the minimization problem yields

$$(19)\quad u_i^* = -\frac{\hat{\gamma}}{[\hat{\gamma}^2 + \mathrm{Var}\,(\hat{\gamma})]}\varepsilon_{pi}.$$

For a given ε_{pt}, this leads to an unambiguously smaller response. In other words, imprecision creates caution, with policy reactions being muted in the face of uncertainty.

Reactions are further attenuated if policymakers attach a cost to the movement in instrument. Taking the same simple setup, imagine the modified objective function

$$(20)\quad \min_{\{u_i\}} E[\hat{p}_i^2 + \alpha \hat{r}_t^2].$$

This produces the reaction function

$$(21)\quad u_i^* = -\frac{\hat{\gamma}}{[\hat{\gamma}^2 + \mathrm{Var}\,(\hat{\gamma}) + \alpha]}\varepsilon_{pi},$$

which will yield an even smoother path for the interest rate than does (19).

Results

I examine results based on several policy objectives. It is worth noting that the exercise described here appears to be a gross violation of the Lucas critique. That is to say, contrary to the implications of the discussion in section I, I assume that the reduced-form correlations among output, prices, and interest rates described by equations (11) and (12) are unaffected by the change in the policymaker's reaction function.

There are two ways to defend the procedure. The first is to take the view of Sims (1982)—that parameters in these models evolve slowly enough to make Lucas-critique considerations quantitatively unimportant. The second defense is to reinterpret the exercise as an attempt to recover the objective function that policymakers were implicitly using, by trying to match the actual federal funds rate path with that implied by an optimal rule.

I report results for three different policy rules. The first, which might be termed passive, holds the federal funds rate fixed in the face of the shock. (The model makes it clear that this is not really a passive policy, since it involves shocks to overcome the estimated reaction function.) The other two, which I will call active, minimize the average MSE of either the log of the price level or the log of nominal output over a 36-month horizon (h = 36).[9] For each rule, I examine three experiments—one for each structural shock. In each of the nine resulting cases, $\varepsilon_{jo} = 1$ and $\varepsilon_{lk} = 0$ for $l \neq j$ and $k \neq 0$. In other words, there is a unit innovation to one of the structural disturbances in the base period, and that is all. I then construct individual estimates for the optimal response of interest rates to each of the shocks.

Figure 4 reports the implied path of the federal funds rate, aggregate prices, and industrial production for each policy objective in response to each of the three structural shocks. The fixed federal funds rate policy results in consistently higher output and prices than does either of the other two polices. The activist policies both have the same profile, whatever the source of the shock. Output and prices both rise initially, and then fall, with output dropping more than prices.

Interestingly, both of the activist policies involve raising the funds rate immediately and then lowering it slowly. This follows directly from the fact that prices respond slowly to policy innovations (see the third row of figure 1). The implication is that a policymaker who wishes to stabilize prices must respond to exogenous shocks quickly, in order to ensure that future price movements are minimized. That is the argument for the Federal Reserve's tightening up at the first sign of upward price pressure.

Comparing Targeting Objectives

These calculations have direct implications for the debate between advocates of price-level targeting and those who favor targeting nominal GDP. To see why, I have computed the implied root-mean-square error (RMSE) for inflation and nominal income for each policy. For the price-targeting case, these are the square root of the minimized objective function (13).

Table 1 shows the results. The computations suggest that nominal-income targeting has a certain robustness, since inclusion of real output in the objective function increases the RMSE for inflation only slightly. For the case of an output shock, the increase is from 0.24 to 0.61. However, when the output shock is the

9 Because the model is estimated in logs, the minimum MSE of the nominal-income policy minimized the MSE of the sum of the log of industrial production and the log of the CPI.

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FIGURE 4

Interest Rate, Output, and Price Paths following Shocks, and the Policy Response

Min MSE (π) policy — Fixed interest rate policy — Min MSE ($\pi + \dot{y}$)

NOTE: Horizontal axes are in months; vertical axes are in the change in the log per month.
SOURCE: Author's calculations.

TABLE 1

Comparison of Policy Responses

Average RMSE of Inflation over a 36-Month Horizon

Policy Rule	Source of Shock: Aggregate Price	Commodity Price	Output
Fixed interest rate	2.35	1.98	1.14
Min MSE ($\pi + \dot{y}$)	2.15	1.50	0.61
Min MSE (π)	0.99	0.51	0.24

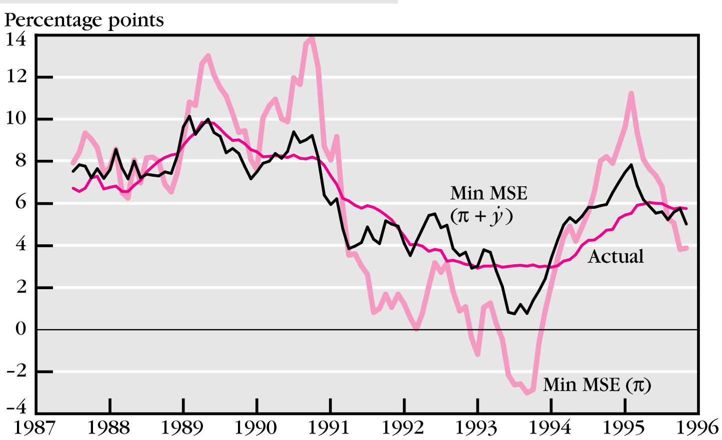
Average RMSE of Nominal Income over a 36-Month Horizon

Policy Rule	Source of Shock: Aggregate Price	Commodity Price	Output
Fixed interest rate	1.86	4.89	6.19
Min MSE ($\pi + \dot{y}$)	0.32	0.35	0.69
Min MSE (π)	0.99	10.85	4.12

SOURCE: Author's calculations.

FIGURE 5

Comparison of Optimal and Actual Federal Funds Rate Paths[a]



a. Monthly data, June 1987 to November 1995.

SOURCES: Author's calculations; and Board of Governors of the Federal Reserve System.

source of the instability, the move from price-level targeting to nominal-income targeting decreases the RMSE of nominal income substantially—from 4.12 to 0.69. In other words, the inability to estimate precisely either the impact of shocks on prices or prices' response to policy innovations argues strongly for including real variables in the objective function.

Comparing Actual and Implied Interest Rate Paths

Finally, one might ask how closely recent policy conforms to what would have been implied by either the price-level or nominal-income targeting rules plotted in figure 5. A simulated interest-rate path can be calculated by taking the estimated structural innovations, the $\hat{\varepsilon}_{jt}$'s, and then computing the optimal policy responses implied by each rule before substituting the result into the equation for the federal funds rate, which is the equivalent of (11).[10]

Figure 5 compares the actual path of the federal funds rate with that implied by the estimated price-level and nominal-income targeting policies. When we examine the figure, several findings emerge. First, targeting the price level alone yields larger swings, as the funds rate reaches both higher and lower extremes. The actual funds rate is the least variable, looking like a smoothed version of the two simulated paths, but the general character of the plot suggests that the optimal policy response simply involves faster, bigger movements than those on the actual path.[11]

Figure 5, however, allows an even more interesting conclusion. From its results, it is possible to infer something about the procedures policymakers were actually following. Such a calculation does not violate the Lucas critique, since it is an attempt to recover the loss function implicit in the policy actions we actually observed.

The estimates imply that the actual funds-rate path was very similar to one that would

10 Performing the calculations in this way ignores a number of elements. In particular, there is no guarantee that the policy rules generated from the artificial experiment of one unit shock in one ε_{jk} at a time will be robust to sequences of shocks in all the ε_{jk}'s simultaneously. One clear reason for this is that it ignores the covariance of estimated coefficients both within and across the elements of the $\hat{A}_{ij}(L)$'s.

11 As one would expect, these large policy innovations result in less stable real output, highlighting that the ultimate issue in policymaking is still the relative weight of prices and output in the objective function.

have been implied by a nominal-income targeting procedure, only smoother. It is as if, over the past decade or so, the federal funds rate had been set to conform to a nominal-income targeting regime, but with policymakers attaching a cost to actually moving the funds rate. That is, the objective function that we can construct from the actual path of interest rates would minimize the sum of squared deviations in nominal income from a target path and squared movements in the federal funds rate, over a horizon of about three years.

IV. Summary

The information requirements for any policy rule are daunting. Not only do policymakers need timely information about current economic conditions, they also need forecasts of the future path of the variables they wish to control (aggregate prices and real output) and quantitative estimates of how their actions will affect these objectives.

This paper's purpose is to suggest that much of our knowledge is very inexact, and that our inability to precisely forecast the results of policy changes should make us cautious. Even more important, the fact that we have a much better understanding of the impact of our policies on real output than on prices suggests that nominal-income targeting rules are more robust than price targeting rules. From a purely pragmatic viewpoint, someone who cares about nominal income is made substantially worse off by moving to a price-level target, which destabilizes real output considerably. Thus, practical issues make a strong argument for nominal-income targeting.

In addition, we have seen that the actual path of interest rates over the past decade is very similar to that implied by a nominal-income targeting rule, albeit one in which interest rate movements are viewed as costly. By comparing the actual interest-rate path with the path implied by the nominal-income targeting rule, we see that policymakers have smoothed interest rate movements more than the rule would have dictated, but not by much.

Appendix: Identification

To understand the more general issues of identification, it is useful to rewrite the four-equation model [(1)–(4)] in a more compact form:

$$\text{(A1)} \qquad x_t = A(L)\,e_t,$$

where x_t and e_t are now vectors, and $A(L)$ is a matrix of lag polynomials. We can also write the model in its more familiar VAR reduced form as

$$\text{(A2)} \qquad R(L)\,x_t = \eta_t,$$

where $R(0) = I$, the η_t's are i.i.d. (implying that they are orthogonal to the lagged x_t's), and $E(\eta\eta') = \Sigma$. It immediately follows that $A(L)e_t = R(L)^{-1}\eta_t$. This allows us to write $A(0)e_t = \eta_t$, and $A(L) = R(L)^{-1}A(0)$. As a result, given estimates of $A(0)$, $R(L)$, and η, we can recover estimates of both the structural innovations—the e_t's—and the structural parameters—the components of $A(L)$.

The issue of identification is the problem of estimating $A(0)$. To show how this is done, note that $A(0)E(ee')A(0)' = \Sigma$, where $E(ee')$ is diagonal by construction. Normalizing $E(ee') = I$, we obtain the result that $A(0)A(0)' = \Sigma$. In a system with n variables, Σ has $[\frac{n(n+1)}{2}]$ unique elements, and so complete identification requires an additional $[\frac{n(n-1)}{2}]$ restrictions. In a four-variable model, six more restrictions are needed. This is a necessary but not sufficient condition for identification. Sufficiency can be established by proving that the restrictions lead to construction of an $A(0)$ matrix that is invertible.

The long-run restrictions of the Galí-style identification can be understood by defining $A(1)$ as the matrix of long-run effects computed by summing the coefficients in $A(L)$. That is, the (i,j) element of $A(1)$ is

$$A_{ij}(1) = \sum_{k=0}^{\infty} a_{ijk}.$$

There are two long-run restrictions. The first is that the impact of ε_{pt} and u_t on y_t is transitory, and so $A_{31}(1) = A_{34}(1) = 0$. The second is that ε_{pt} and u_t have no permanent impact on the relative price of commodities, $(p_{ct} - p_t)$, that is, $A_{11}(1) - A_{21}(1) = A_{14}(1) - A_{24}(1) = 0$.

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